NASA SBIR Subtopic:

S2.03
S2.04
ES.02

H. Philip Stahl, Ph.D.
Sub-Topic Manager

NASA 'Optics' Award Statistics Total

	Phase 1	Phase 2
2005	21% (8/38)	71% (5/7)
2006	28% (8/29)	63% (5/8)
2007	36% (4/11)	50% (2/4)
2008	59% (10/17)	50% (4/8)
2009	56% (9/16)	50% (4/8)
2010	50% (11/22)	11% (1/9)
2011	28% (7/25)	20% (1/5)
2012	28% (8/29)	50% (4/7)
2014	54% (7/13)	33% (2/6)
2015	48% (10/21)	
Total	37% (82/221)	45% (28/62)

SBIR Sub-Topics

In 2015 NASA re-worked the S2 subtopics:

S2.03 “Advanced Optical Systems for UVO & IR”

S2.04 “X-Ray Mirrors, Coatings and Free-Form”

ES.02 “Adv Tech Telescope for Balloon Mission”

In 2016, the topic remain essentially unchanged.

Except, ‘Select’ balloon and suborbital subtopic has been merged into ‘Standard’ S2.03 and S2.04 subtopics.

S2.03 "Advanced Optical Systems for UVO & IR"

	Phase 1	Phase 2
2015	50% (5/10)	
Total	50% (5/10)	

S2.04 “X-Ray Mirrors, Coatings and Free-Form”

	Phase 1	Phase 2
2015	45% (5/11)	
Total	45% (5/11)	

“Advanced Optical Systems” Award Statistics

	Phase 1	Phase 2
2005	22% (2/9)	100% (1/1)
2006	29% (6/21)	50% (3/6)
2007	33% (1/3)	100% (1/1)
2008	75% (3/4)	50% (1/2)
2009	66% (2/3)	66% (2/3)
2010	33% (4/12)	00% (0/3)
2011	33% (4/12)	00% (0/3)
2012	30% (3/10)	33% (1/3)
2014	66% (2/3)	100% (1/1)
Total	35% (27/77)	43% (10/23)

“Optical Manufacturing & Metrology” Award Statistics

	Phase 1	Phase 2
2005	21% (6/29)	67% (4/6)
2006	25% (2/8)	100% (2/2)
2007	38% (3/8)	33% (1/3)
2008	54% (7/13)	50% (3/6)
2009	46% (6/13)	33% (2/6)
2010	70% (7/10)	17% (1/6)
2011	23% (3/13)	50% (1/2)
2012	20% (3/15)	66% (2/3)
2014	50% (5/10)	20% (1/5)
Total	35% (42/119)	44% (17/39)

ES.02 “Adv Tech Telescope for Balloon Mission”

	Phase 1	Phase 2
2012	50% (2/4)	100% (1/1)
2015	0% (0/0)	
Total	50% (2/4)	100% (1/1)

2015 SBIR S2.03 'Normal Incidence'

Phase I 10 Submitted 5 Funded

- **Additive Manufactured Very Light Weight Diamond Turned Aspheric Mirror;** Dallas Optical Systems, Inc.
- **High Performance Consumer-Affordable Nanocomposite Mirrors with Supersmooth Surfaces, Precise Figuring, and Innovative 3D Printed Structures;** Lightweight Telescopes, Inc.
- **Additive Manufacturing for Lightweight Reflective Optics;** Optimax Systems, Inc.
- **Ultra-low Cost, Lightweight, Molded, Chalcogenide Glass-Silicon Oxycarbide Composite Mirror Components;** Semplastics EHC, LLC
- **Diffusion Bonded CVC SiC for Large UVOIR Telescope Mirrors and Structures;** Trex Enterprises Corporation

Phase II TBD Submitted TBD Funded

NASA SBIR/STTR Technologies

S2.03-9125 - Additive Manufactured Very Light Weight Diamond Turned Aspheric Mirror

PI: John Casstevens

Dallas Optical Systems, Inc. - Rockwall, TX

Identification and Significance of Innovation

Direct Metal Laser Sintering(DMLS)is an additive mfg. process which allows extremely thin wall complex structures. Off-axis asphericss as easily produced as simple spherical surfaces.
Ni13%P alloy is the only hard, fine grain, material for diamond turned and polish to ultra smooth surfaces. Diamond turning produces aspheric surfaces to visible optical tolerances. Low force of diamond turning allows mirror very thin faceplate without print through of the inner structure.
The innovation uses steel,and superalloy AM to make mirror substrates with critically important near perfect thermal expansion match with electroplated NiP coating. For fabrication of low cost, light weight large mirrors by three processes. 1.Additively mfg. mirror substrates very close to net shape.
2.Electroplated NiP alloy covers contours of mirror substrates with enough thickness to allow D.T. with no machining of mirror substrate required.
3.Dia. turning can produce a mirror contour to visible tolerance.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 5)

Technical Objectives and Work Plan

— DOS will design the mirror substrate and internal support structure to be additively manufactured to optimize stiffness and minimize areal density consistent with suitable strength and lowest possible cost.

— Work closely with Solid Concepts, using their DMLS/SLM machines to build development mirror substrates and test samples suited for study of precision optical uses.

— Work with our long time electroplating vendor ENI/RHEDCO in Huntsville, Al to electroplate the additively manufactured mirror substrates. Electroformed Nickel (ENI/RHEDCO) has provided plating and electroformed NiP lightweight mirror development items for Dallas Optical Systems that were used in previous Phase I and Phase II NASA SBIR projects.

— At DOS, conduct heat treatment studies and metallurgical inspection of superalloy, steel and stainless steel sample materials working with Solid Concepts DMLS to evaluate residual stresses and dimensional stability.

— DOS will diamond turn and polish additively manufactured superalloy mirror substrates that have been electroplated with NiP alloy by ENI/RHEDCO.

NASA Applications

Initial medium aperture off-axis three mirror anastigmat (TMA) mirror optical components, collimator and telescope optical instruments. As size capability increases, larger off-axis TMA optical collimator and telescopes. Off-axis hexagonal periphery aspheric optical mirrors can be assembled to enable very large telescopes.

Non-NASA Applications

Defense applications requiring mirror optical components for satellites and aerospace vehicles. Non-military applications such as weather satellite optical mirrors and commercial telescope optics. Commercial applications requiring light weight stiff optical components such as semiconductor manufacturing equipment.

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NON-PROPRIETARY DATA

NASA SBIR/STTR Technologies

S2.03-8703 - High Performance Consumer-Affordable Nanocomposite Mirrors with Supersmooth Surfaces, Precise Figuring, and Innovative 3D Printed Structures

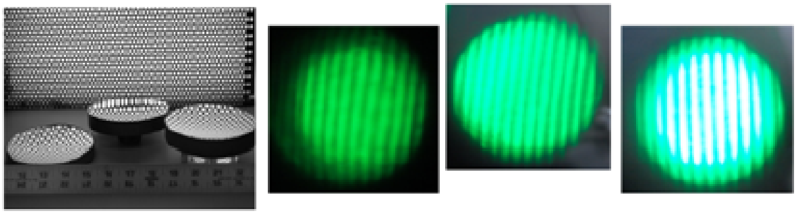
PI: Peter Chen

Lightweight Telescopes, Inc. - Columbia, MD

Identification and Significance of Innovation

Lightweight Telescopes, Inc. proposes to demonstrate performance, advance the TRL, and initiate commercialization of nanocomposite optics technology. This new technology is based on carbon nanotubes, various powders and fibers, polymers, and a proprietary process to craft precisely shaped and supersmooth optical surfaces. The technology is truly low cost in that mirrors can be marketed to consumers. Other capabilities include rapid fabrication, multiple identical units, 'smart' optics and structures, and in-space fabrication of very large aperture optics. The significance of this innovation is that nanocomposite optics technology can, with the infusion of advanced numerical modeling and state-of-the-art 3D printing techniques, be developed into an enabling technology for future NASA programs with across-the-board applications spanning the range from very small missions (CubeSat) to very large ones (TPF, Planet Imager, Space EELT).

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)



Technical Objectives and Work Plan

The overall technical objective of this proposal is to advance TRL and demonstrate the viability and some of the capabilities of nanocomposite mirrors. The work is divided into sub-tasks as follows:

1. Fabricate 15cm mirrors for proof-of-concept and for commercialization
2. Use a proprietary non-contact process to craft diffraction limited 15 cm mirrors with supersmooth surfaces
3. Vacuum coat 15 cm mirrors. Field test in an astronomical telescope
4. Use advanced numerical modeling techniques (topology optimization) to design nanocomposite support structures with optimized stiffness/mass ratios
5. Fabricate support structure by 3D printing
6. Fabricate 25 cm mirrors with integrated support structures

NASA Applications

Nanocomposite optics technology, by virtue of its tremendous versatility and truly low cost, can be an enabling technology for NASA missions ranging from the very small (CubeSats) to the very big (TPF, space EELTs). Specific examples include:
Off-the-shelf meter class UVOIR telescopes for Earth observing
Large Solar Telescope
Large segmented mirror telescopes (e.g ATLAS)
Large area grazing incidence mirrors for X-ray astronomy
Space telescopes with smart mirrors and smart structures

Non-NASA Applications

Potential Non-NASA Applications
* DoD
* 0.5 m telescopes for amateur astronomy
* 'Moondust' telescopes for schools. Museums, public outreach
* 1-2 m class research telescopes for small college observatories
* 0.5-1 m deformable mirrors with continuous and supersmooth surfaces

Firm Contacts

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NASA SBIR/STTR Technologies

S2.03-9591 - Additive Manufacturing for Lightweight Reflective Optics

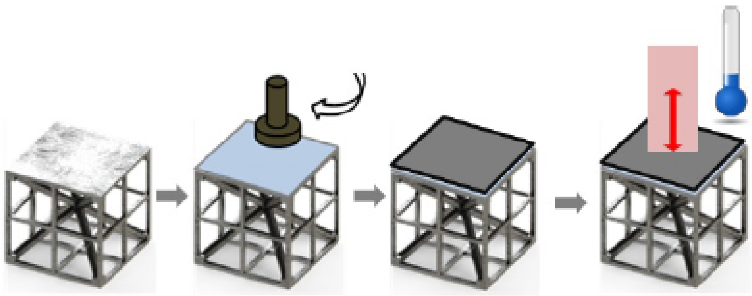
PI: Matthew Brunelle
Optimax Systems, Inc. - Ontario, NY

Identification and Significance of Innovation

Our proposed innovation is additive manufacturing for the production of lightweight mirror substrates for flight applications with high mechanical stability. The steps of our proposed process for manufacturing lightweight 3D printed mirrors: first, a geometrically complex substrate is easily and cost-effectively manufactured using 3D printing. After printing, the mirror surface is lapped and polished using traditional manufacturing methods to final figure specifications. Then, a flight or space ready mirror coating at the necessary wavelength is applied to the surface and the part is tested for performance.

Additive manufacturing will permit lightweight mirrors with support structures that are impossible with traditional manufacturing methods for lightweighting. In addition, these structures will be optimized in size, shape, and location to negate thermal effects from changes in temperature and mechanical effects from stresses during manufacture, mounting, and flight.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)



Technical Objectives and Work Plan

Objective 1: Demonstrate feasibility of additive manufacturing a lightweight substrate with mechanical and thermal stability at flight temperatures

Our goal for this objective is to manufacture a spherical mirror substrate suitable for light focusing applications at a range of temperatures for flight applications. In this manner, we attempt to design the substrate to have little deformation as the temperature changes from room temperature to the temperatures of flight.

Objective 2: Demonstrate feasibility of depositing mirror coatings at low temperatures for flight applications

A low temperature deposition process minimizes shape distortion of the 3D-printed substrate that can occur during a typical high-temperature coating process. To qualify the coating for flight applications requires verifying the desired optical & mechanical performance in vacuum, after temperature cycling, as well as after UV, ionized plasma, and radiation exposure.

Our work plan consists of the following tasks:
1: Mirror Substrate Design and Optimization
2: Manufacturing of the Optimized Mirror Substrate using 3D printing
3: Polishing the Mirror Substrate

NASA Applications

Many missions in space and sub-orbital atmosphere require lightweight telescope systems for imaging applications. Balloon missions are a specific application that would be perfect for lightweighted 3D printed mirrors. Additionally, the Astro2010 report identified that lightweight mirrors for both x-ray and UV/Visible applications are necessary for several different future missions. A lightweighted 3D printed optic could dramatically change the design space for the mirror in these missions.

Non-NASA Applications

Using mirror coated 3D printed optics for airborne laser systems would provide a significant opportunity to advance the performance by reducing the weight of the optical assembly. 3D printing of mirror substrates for freeform optics would expand the possible design space of freeform surfaces.

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NASA SBIR/STTR Technologies

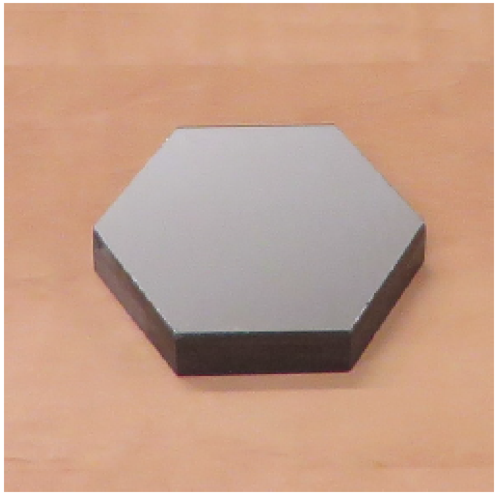
S2.03-9856 - Ultra-low Cost, Lightweight, Molded, Chalcogenide Glass-Silicon Oxycarbide Composite Mirror Components

PI: William Easter
Semplastics EHC LLC - Oviedo, FL

Identification and Significance of Innovation

Semplastics will develop and produce a lightweight, molded composite mirror component that will achieve an order of magnitude reduction in areal cost for both UV/Optical and IR NASA missions. The innovative composite structure of a chalcogenide glass coating with a silicon oxycarbide mirror substrate provides a path to make monolithic or segmented primary mirrors with significant reduction in on-orbit mass and in energy required for manufacture. This low-risk development builds on Semplastics' existing composite technology and provides a cost effective path to produce larger primary mirrors for future space-observing and Earth-observing missions. Specific innovations of this approach include: 1) the use of bulk molded polymer-derived ceramic silicon oxycarbide as the mirror substrate; 2) the use of chalcogenide glass to seal the pores of the bulk silicon oxycarbide substrate; and 3) the additional use of chalcogenide glass to produce a flat and smooth surface for metallization.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)



Technical Objectives and Work Plan

Semplastics will design, fabricate, and test a 25cm molded silicon oxycarbide blank mirror substrate. In addition, blank silicon oxycarbide disks will be provided to Semplastics' subcontractor, the University of Central Florida (UCF). UCF will demonstrate a cost-effective chalcogenide glass process to seal the porous silicon oxycarbide top surface and provide a flat, smooth surface for the final mirror metallization process. Semplastics anticipates the results of this Phase I effort will validate the feasibility and benefits of the chalcogenide glass-silicon oxycarbide mirror component, advancing the Technology Readiness Level (TRL) from 2 to 3. Using the knowledge and experience gained in Phase I, Phase II will focus on making 0.5m mirrors and improving the TRL to 4 or 5.

NASA Applications

1. Orbital telescopes and space observation platforms, including future space-observing missions such as Euclid
2. Future Earth-observing missions such as the Climate Absolute Radiance and Refractory Observatory (CLARREO)

Non-NASA Applications

1. Earth-observation platforms for the Department of Defense and other agencies / entities
2. Ground-based large-aperture, multi-segmented telescopes such as the 39-meter European Extremely Large Telescope (E-ELT) and the 74-meter Colossus telescope

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NASA SBIR/STTR Technologies

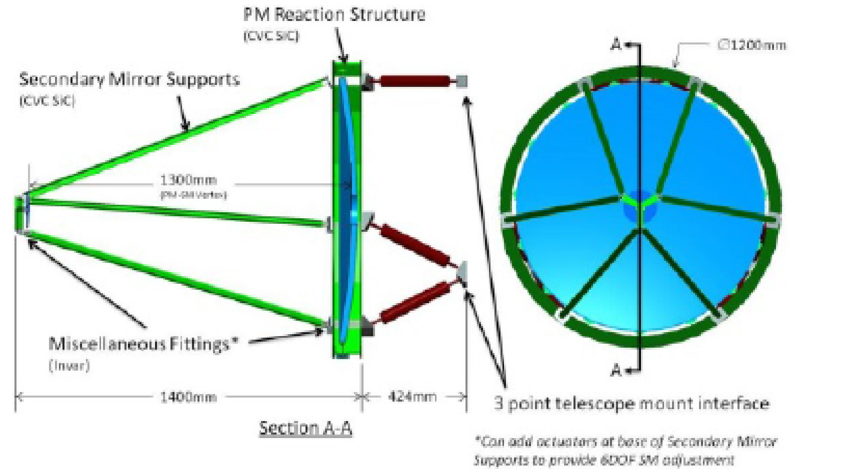
S2.03-9297 - Diffusion Bonded CVC SiC for Large UVOIR Telescope Mirrors and Structures

PI: Lauren Bolton
Trex Enterprises Corporation - San Diego, CA

Identification and Significance of Innovation

Trex proposes to demonstrate a novel solid state ceramic joining technology to produce complex multi-meter aperture primary mirror, or optical bench, or Surrier telescope truss structures by joining smaller, easily manufactured, and simply shaped components. Component mirror segments are substantially polished before joining. This Additive Manufacturing process minimizes schedule intensive machining processes, labor hours, polishing time, and metrology, which in turn dramatically decreases the cost of the multi-meter aperture mirrors. This technology will allow NASA to match/exceed the 4-meter monolithic silicon carbide mirror capability witnessed by Dr. Phil Stahl on his 2014 China visit. The Trex 1.5-meter deposition chamber would be used to generate large hexagonal mirror substrate blanks which are solid state bonded to produce monolithic, multi-meter aperture mirrors (> 4.5-meter), as well as to produce the components for the telescope opto-mechanical support structures.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 5)



Technical Objectives and Work Plan

Dave Baiocchi (RAND) and Dr. Phil Stahl (NASA MSFC) recommended mirror development to the ASTRO 2010 committee and noted several challenges to be overcome for mirrors supported by key analysis results: 1) Scaling James Webb Space Telescope (JWST) diameter by 2X (6.5m to 13m) results in a decrease in stiffness of 4X; 2) The areal density doubles; 3) To achieve the original stiffness then requires the thickness of the mirror to double resulting in another factor of 2X in areal density; 4) Segment gaps result in diffraction and reduced optical throughput; 5) Ground testing, hardware & metrology become significantly more complex, and gravity sag increases by 4X. Trex understands these challenges and has developed manufacturing technology advancements for our silicon carbide, including replication, and now solid state bonding. Trex's overarching objective in Phase I is to demonstrate a reliable, cost-effective manufacturing capability for multi-meter class CVC SiC® optics and opto-mechanical structures using solid state bonding technology. Our approach would eliminate segment gap concerns. Our approach of polishing small mirrors and then solid state bonding will greatly offset concerns 1-3, and 5 from above since smaller segments are comparatively stiffer and can handle the polishing pressures needed to obtain UVOIR quality. We will characterize the solid state CVC SiC bond, make bond improvements to eliminate porosity, and then make a subscale demonstration joined mirror.

NASA Applications

Trex CVC SiC® represents an extraordinary technology investment opportunity for NASA with respect to near-term balloon-borne stratospheric telescopes for Astrophysics and Planetary science (GHAPS, BENI, etc), and farther term EUOVIR telescopes such as ATLAST observatory.

Non-NASA Applications

Applications include complex telescopes for Astronomy, Remote Sensing, ISR Missions, police and paramilitary units, fire fighters, power and pipeline monitoring, search and rescue, atmospheric and ocean monitoring, imagery and mapping for resource management, and disaster relief and communications. The dual-use nature of complex telescopes will bring affordability to national defense missions.

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2015 SBIR S2.04 'X-Ray & Freeform'

Phase I 11 Submitted 5 Funded

- **Low Coherence, Spectrally Modulated, Spherical Wavefront Probe for Nanometer Level Free-Form Metrology**; Apre Instruments, LLC
- **Precollimator Manufacturing for X-ray Telescopes**; Mindrum Precision, Inc.
- **Freeform Optics: A Non-Contact "Test Plate" for Manufacturing**; Optimax Systems, Inc.
- **Manufacture of Monolithic Telescope with a Freeform Surface**; Optimax Systems, Inc.
- **InTILF Method for Analysis of Polished Mirror Surfaces**; Second Star Algonumerix

Phase II TBD Submitted TBD Funded

NASA SBIR/STTR Technologies

S2.04-9249 - Low coherence, spectrally modulated, spherical wavefront probe for nanometer level free-form metrology

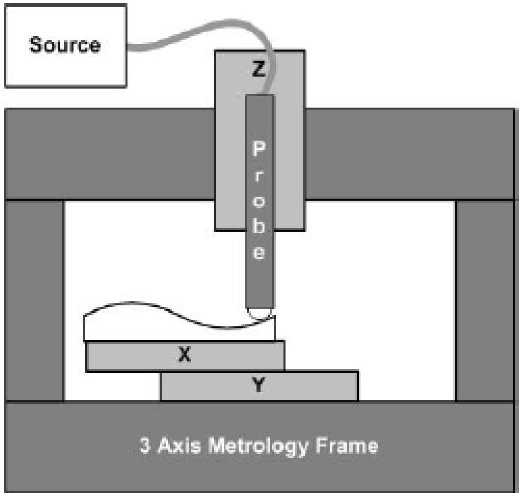
PI: Artur Olszak
Apre Instruments, LLC - Tucson, AZ

Identification and Significance of Innovation

Apre Instruments proposes (Phase I) a novel low coherence, sub-nanometer sensitive interferometric PROBE for rapid measurement of free-form optical surfaces with slopes up to 60 degrees. With sensitivity over 60 degrees, a simple 3-axis metrology frame can be utilized enabling nanometer level measurement uncertainty in the Phase II surface profiler.

Future NASA low-cost science and small-sized payload missions require free-form and conformal optics. Free-form optics are not readily available as inadequate metrology tools limit their manufacture. Traditional interferometers, contact profilers, and multi-axis optical probe based systems lack the accuracy required. This innovation will lead to readily available free-form and conformal optics.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 5)



Technical Objectives and Work Plan

OBJECTIVE: Build a working measurement breadboard system to test and optimize the probe technology regarding nanometer level sensitivity over wide angles.

WORK PLAN

1. Build a broad-band spectrally modulated source to produce a stable localized fringe pattern in a common path interferometer.

2. Design and build a novel optical probe using spectrally controlled interferometry to detect optical surfaces with sub-nanometer resolution at up to 45 degree surface slopes.

3. Validate the surface detection and tracking method utilizing the system breadboard. The target parameters are nanometer resolution and better than 10KHz data rate.

4. Integrate tasks 1, 2, and 3 into a probe system

5. Construct the breadboard test: Design and validation of data processing algorithms and data acquisition electronics, and integrating the probe into a single axis metrology frame.

NASA Applications

Free-form optics, provide the means to create small, lightweight imaging and projection optical systems. These types of optical components are important to NASA present and future missions. No process control metrology tools are available that are capable of measuring these free-form optics to nanometer levels. Thus high accuracy free-form optics cannot be manufactured today. The Phase I PROBE enables nanometer RMS free-form optical manufacture.

Non-NASA Applications

Cell phones, tablets, and laptops utilize free-form optics. Security cameras, fire control systems, defense and medical imaging, projection systems and illumination optics for LED and automobiles all use free-form optics for performance gains. Metrology of free-form surfaces limits the performance of these optics. The Phase I PROBE enables free-form optical manufacture.

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NASA SBIR/STTR Technologies

S2.04-9666 - Precollimator Manufacturing for X-ray Telescopes

PI: Anthony Pinder
Mindrum Precision, Inc. - Rancho Cucamonga, CA

Identification and Significance of Innovation

Space-based x-ray telescope (XRT) astronomical missions currently rely on a precollimator (PC) to reduce stray light. This PC is placed precisely onto the reflector mirror shell to reduce off-axis X-ray photons that leads to a "ghost" image within the detector field of view. Mindrum Precision is proposing a new method to build a PC using emerging Additive Manufacturing (AM) and wire Electric Discharge Machining (EDM) technologies, one that has several advantages over the current PC technology. This proposed PC will be lighter, have a larger open collection area, have lower surface reflectivity and have higher mechanical rigidity. And it can be made with a lower cost on a shorter timeline than the current PC technology, using cutting-edge manufacturing techniques. This innovation is in direct support of the Presidential order of "Encouraging Innovation in Manufacturing" and further advances the manufacturing techniques used in support of Flight instruments for NASA XRT missions.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)

Technical Objectives and Work Plan

The technical objectives are to (1) determine the feasibility of a new and easier method of manufacturing a precollimator (PC) that will reduce the amount of stray light while maximizing the photon collecting area of the detector, (2) determine which of the two AM methods is better in the manufacture of this PC: Direct Metal Laser Sintering (DMLS) or Electron Beam Melting (EBM) and (3) determine design and manufacturing limits of Additive Manufacturing (AM) and wire Electric Discharge Machining (EDM) in the manufacturing of this PC.

In order to achieve the technical objectives described above Mindrum Precision has divided the project into four major areas:
1. Design and Modeling: Engineer the Test Article and Test Article blank in SolidWorks.
2. Additive Manufacturing: Build the Test Article blanks via two separate AM methods in preparation for wire EDM.
3. Electric Discharge Machining: Machine the Test Articles.
4. Inspection and Review: Evaluate the differences between the two AM methods and evaluate the limitations of the wire EDM machining process.

NASA Applications

There is a chronic need for precollimators (PCs) for all space-based x-ray telescopes (XRTs) and thus this innovation would potentially support all of them with an entirely new way of manufacturing the stray-light shielding structure. NASA missions that would be positively affected would be ones like NuSTAR, WHIMEX and SMART-X, all of which are XRT missions that utilize a PC.

Non-NASA Applications

There is a chronic need for precollimators (PCs) for all space-based x-ray telescopes (XRTs) and thus this innovation would potentially support all of them with an entirely new way of manufacturing the stray-light shielding structure. Non-NASA missions that would be positively affected would be ones like ESA's Athena and JAXA's ASTRO-EII, ASTRO-H, DIOS and FFAST.

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NASA SBIR/STTR Technologies

S2.04-9355 - Freeform optics: a non-contact "test plate" for manufacturing

PI: Brian Myer
Optimax Systems, Inc. - Ontario, NY

Identification and Significance of Innovation

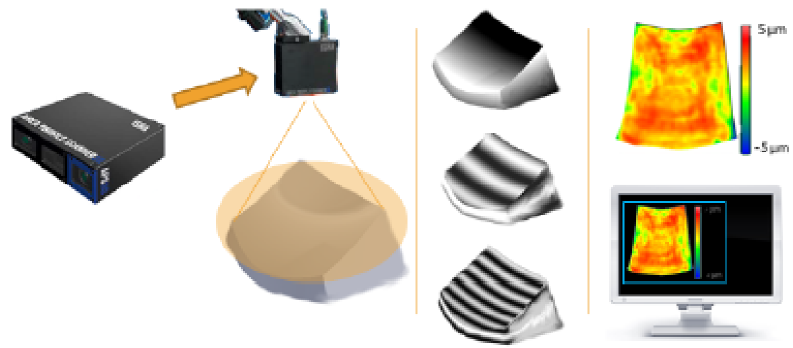
The goal of this NASA SBIR Phase I study is to determine the feasibility of measuring precision (fractional wave) freeform optics using non-contact areal (imaging) optical sensors measuring slope data.

Fabrication of a physical "test plate" for each freeform design is impractical and cost prohibitive.

The proposed innovation is a non-contact metrology method for manufacture of precision freeform optical surfaces; a tool to play the role of the test plate in conventional optical testing. Once implemented into the freeform manufacturing process, this procedure has great potential to streamline processing while increasing the manufacturing technician's information about surface condition during production.

NASA and many agencies and companies have a stated critical need for high-quality freeform optical components, and will benefit from improvements

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)



Technical Objectives and Work Plan

Technical objective 1: Determine limits of applicability of non-contact, imaging metrology tool(s) (material, surface condition, process stage, geometry, fixture, etc.)

Technical objective 2: Provide evidence for validity of results within limits of applicability

a. Using a reference standard or internally generated test part
b. By comparison with existing in-house and external metrology tools routinely used in manufacturing.
c. Determine feasibility of form correction performed based on this measurement method

Our work plan includes:
- Planning, reporting, procurement
- Specifation and - Implementation of metrology tool(s)
- Define (explore) limitations of applicability
- Refine method
- Measurements
- Data mapping
- Validate with reference
- Determine feasibility of form correction using method

NASA Applications

Telescope and imaging system optics, including components and correctors. Optics manufactured from glass, crystal materials and ceramics.

Non-NASA Applications

Freeform optics are quickly becoming part of many commercial and military optical systems. Many optical designers are starting to use freeform optics to achieve optical performance (less aberrations), lighter weight optical systems through a reduced number of components, and an increased ability to go off axis with smaller and tighter packages.

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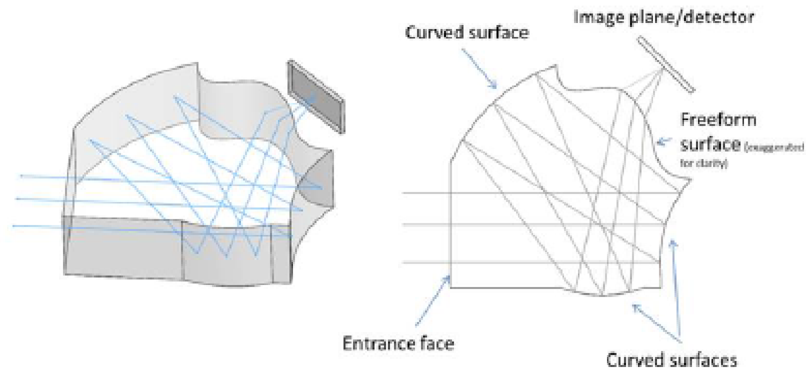
NASA SBIR/STTR Technologies

S2.04-9683 - Manufacture of Monolithic Telescope with a Freeform Surface

PI: Todd Blalock
Optimax Systems, Inc. - Ontario, NY

Identification and Significance of Innovation

Monolithic freeform telescopes offer the potential to positively address the size, weight and vibration concerns associated with flight telescope systems. We propose to prove feasibility that our optics manufacturing process is capable of producing of a freeform optical telescope system by manufacturing and testing four optical surfaces on four sides of a single high purity optical material. The resulting working monolithic telescope will include a high precision freeform surface. The capability of in adding of a freeform surface in a monolithic optical telescope design offers flexibility to create more compact designs, larger fields of view, and better-performing unobscured systems.



Estimated TRL at beginning and end of contract: (Begin: 3 End: 5)

Technical Objectives and Work Plan

We will design and manufacture a simplified monolithic optical telescope with a freeform surface and study the suitability of using existing high purity fused silica as the substrate for the monolith. The manufacturing process will be investigated and optimized to produce a single monolithic telescope and its optical and imaging properties studied to provide feedback to tune the manufacturing process.

Work Plan:
Design optical system as off-axis telescope with freeform corrective surface.
Develop and optimize manufacturing process to produce freeform surface onto monolithic high purity fused silica
Characterize and test final optical assembly

NASA Applications

Space-borne / air-borne telescopes
Exo-planet direct imaging telescopes
Cubesat and nano-sat optical system payloads
G-force/ mis-aligment resistant optical assemblies

Non-NASA Applications

Freeform optics has revolutionized optical design in non-imaging and imaging applications. Markets such as LED and auto illumination, heads ?up displays for commercial and military applications, biomedical optical systems, and all fields where compact and high-performance imaging in a compact and alignment-free design is desired.

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NASA SBIR/STTR Technologies

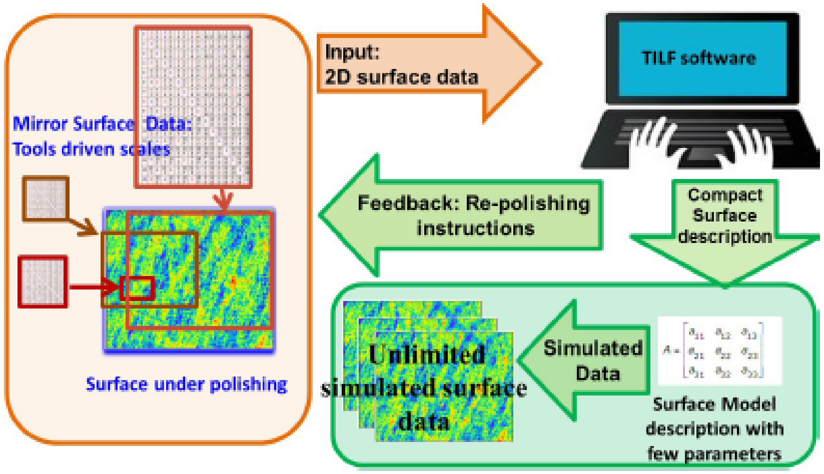
S2.04-9193 - InTILF Method for Analysis of Polished Mirror Surfaces

PI: Anastasia Tyurina
Second Star Algonumerix - Needham, MA

Identification and Significance of Innovation

Development of new generation of NASA x-ray optical systems relies on x-ray optics of unprecedented quality with surface slope precision of 0.1-0.2 µrad and surface height error of 1 nm.1-5. This expensive optics fabrication creates a requirement to provide the compact model for it based on existing metrology data. We will develop a tool to optimally characterize and generate a 2D surface with spectral fidelity. The tool can be incorporated into polishing tools to improve the polishing process.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)



Technical Objectives and Work Plan

The goal of the project is to develop a software tool for compact statistical 2-dimentional surface modeling with high spectral fidelity. Second Star team has developed a statistical foundation for a similar tool for 1-dimentional data. We propose three main technical objectives:
1)One-dimensional software development. Performance will prove theoretical results and deliver a functioning tool for profile analysis. The tool will perform with better statistical and spectral fidelity than existing ARMA-based, tools reducing the residual error by as much as 50%.
2)Develop a method of generation of variety of surfaces of statistical characteristics similar to the given profile. Performance of the software will prove generation of statistically equivalent surface data as well as deliver a functioning tool for profile generation.
3)Develop the statistical foundation of the generalization of the method to two dimension. The theoretical derivation will prove that the method can be extended random two dimensional fields.
Work Plan: 1. Select surface profile data for testing and evaluation of the one dimensional software. 2. Develop a Matlab based software for optimal InTILF filter. 3. Testing and evaluation of the software. 4. Develop generation method for statistically similar profiles. 5. Testing and evaluation. 6. Develop theoretical foundation for generalization of the one dimensional to two dimensional random planar fields. 7. Market research for commercialization. 8. Reports

NASA Applications

The envisioned analytic software will facilitate development of new x-ray optics of unprecedented quality with surface slope precision of less than 0.1-0.2 µrad and surface height error of less than 1 nm.1-5 generation. Expensive optics fabrication creates a requirement to provide compact characterization based on existing data. We will develop theoretical base & software tools to capture surface morphology and enable the user to generate random similar surfaces for performance prediction.

Non-NASA Applications

InTILF will facilitate development of surface analysis, modeling, & interpolation of sparsely sampled surfaces. It can be used for front- and back-end quality control in fabrication of optics or lithography, for cartography and seafloor interpolation, etc. InTILF will capture statistical properties of surfaces & enable the user to generate random statistically equivalent surfaces for testing.

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2014 SBIR S2.03

Phase I 3 Submitted 2 Funded

Broad-Band Reflective Coating Process for Large UVOIR Mirrors, ZeCoat

Advanced Mirror Material System, Peregrin Falcon

Phase II 1 Submitted 1 Funded

Advanced Mirror Material System, Peregrin Falcon

NASA SBIR/STTR Technologies

S2.03-9217 - Advanced Mirror Material System

PI: Robert Hardesty
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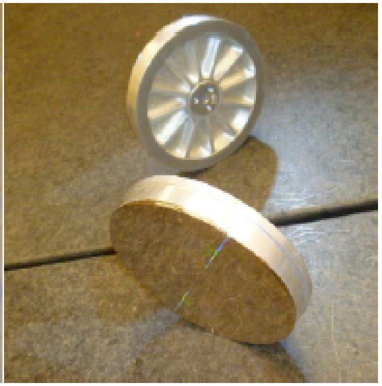
Identification and Significance of Innovation

Future NASA Science Missions will need innovative technology for cost effective, high performance telescopes for astrophysics and Earth science. Some missions will require large aperture, lightweight, highly reflective mirrors/optics while others may require operation at cryogenic temperatures. Also required are large x-ray imaging mirrors for future space based x-ray observatories. Innovative materials and processes are required to provide cost effective mirrors that can be produced timely. This SBIR effort explores an innovative material system to produce mirrors by matching the coefficient of thermal expansion of electroless nickel to the compatible, lightweight, high stiffness, stable substrate material; Be-38Al (AMS 7911). Matching the CTE of electroless nickel by altering the phosphorous content of the plating solution to Be-38Al provides a stable substrate with an amorphous surface that can be single point diamond turned to optical requirements.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 6)



Technical Objectives and Work Plan

-To reduce the cost of space borne mirrors by a factor of over 4 while cutting production time in half.
-Maintain stiffness, low density, and performance while reducing cost.
-Be able to produce optics > 8 m in size.
-Gain over a 2.5% increase in surface area. Provide the full use of the optic, all the way to the edge without a roll off like conventional polishing which loosens the outer band of the surface.
-Have a system that can be applied to UV/optical systems along with x-ray/neutron systems.
-Provide a stable and precision optical system that can enable x-ray telescopes to reach accuracies of less than 1 arc second.
-Maintain optical system performance with surface roughnesses of less than 5 nanometers RMS (50 Angstroms RMS).
-Utilize existing emittance and absorptivity coatings within the design of this advanced material system allowing for traditional and typical thermal control as well as environmental control.
-Provide a conventional means to integrate the mirrors into their subsequent assemblies.
-Provide an electroless nickel coating that matches the coefficient of thermal expansion of Be-38Al down to cryogenic temperatures.
The 24 month work plan is comprised of 11 Tasks that systematically and empirically derives, reduces, demonstrates and then presents the data

NASA Applications

-Astrophysics applications that require large aperture, lightweight and highly reflective mirrors that can operate down to cryogenic temperatures.
-Lightweight x-ray imaging mirrors for future large advanced x-ray observatories.
-Could enhance programs like AFTA/WFIRST, JUICE, ASTRO, EVI and possibly Euclid.

Non-NASA Applications

-Optical systems for Earth surveillance, both visible and infrared.
-Terrestrial high performance mirror systems. (Fast response).
-High performance scanners and observation mirrors.
-Laser and interferometer measuring systems.

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2014 SBIR S2.04

Phase I 10 Submitted 5 Funded

- **Figuring and Polishing Precision Optical Surfaces,** OptiPro
- **Manufacture of Free-Form Optical Surfaces with Limited Mid-Spatial Frequency Error,** Optimax
- **Optical Metrology of Aspheric and Freeform Mirrors,** OptiPro
- **Innovative Non-Contact Metrology Solutions for Large Optical Telescopes,** SURVICE Engineering
- **Monolithic Gradient Index Phase Plate Array,** Voxtel

Phase II 5 Submitted 1 Funded

- **High Performance Computing-Accelerated Metrology for Large Optical Telescopes**, SURVICE Engineering

NASA SBIR/STTR Technologies

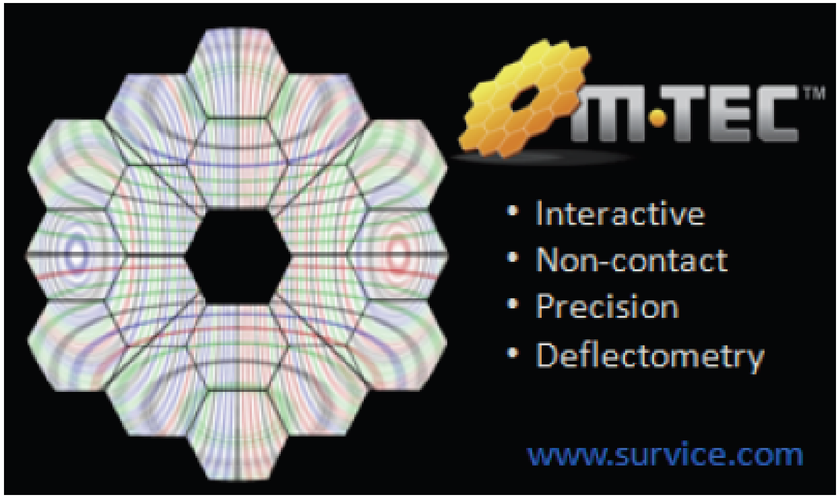
S2.04-9255 - High Performance Computing-Accelerated Metrology for Large Optical Telescopes

PI: John Ebersole
SURVICE Engineering Company, LLC - Belcamp, MD

Identification and Significance of Innovation

NASA has unique non-contact precision metrology requirements for dimensionally inspecting the global position and orientation of large and highly-polished multi-segmented mirrors (in an as-installed configuration), such as those used on the James Webb Space Telescope. SURVICE Metrology has assembled a world-class team of metrologists and optical physicists to develop M-TEC, an innovative non-contact metrology solution that extends traditional deflectometry for determining reflective-surface profiles by combining pattern matching and high performance computing techniques.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 7)



Technical Objectives and Work Plan

The primary objective of the Phase II work plan is to develop, demonstrate, and validate the proposed M-TEC non-contact deflectometry technology, advancing the state-of-the-art in precision metrology for highly-polished reflective mirror.

NASA Applications

With segmented mirrors being the likely or preferred type of construction for most future large optical telescopes, there will be many opportunities to employ the SURVICE metrology solution on NASA telescope programs, to include the James Webb Space Telescope (JWST), the Wide-Field Infrared Survey Telescope (WFIRST), and the Advanced Technology Large-Aperture Space Telescope (ATLAST).

Non-NASA Applications

The manufacturing of DoD, NASA, and international space program telescopes is performed by numerous Original Equipment Manufacturing (OEM) firms. These firms support a broad spectrum of customers that include but are not limited to the NASA. SURVICE has already identified both US and international partners that are interested in the proposed technology development.

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Any Questions?

NASA 2016 SBIR Subtopic:

S2.03 "**Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope**"

H. Philip Stahl, Ph.D.

Sub-Topic Manager

Generic Instructions to Proposer

Define a customer or mission or application and demonstrate that you understand how your technology meets their science needs.

Propose a solution based on clear criteria and metrics

Articulate a feasible plan to:

- fully develop your technology,
- scale it to a full size mission, and
- infuse it into a NASA program

Deliver Demonstration Hardware not just a Paper Study, including :

- documentation (material behavior, process control, optical performance)
- mounting/deploying hardware

S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope

Subtopic solicits solutions in the following areas:

- **Components and Systems for potential EUV, UV/O or Far-IR missions**
- **Technology to fabricate, test and control potential UUV, UV/O or Far-IR telescopes**
- **Telescopes that enable sub-orbital rocket or balloon missions.**

Subtopic's emphasis is to mature technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies.

Ideal Phase 1 deliverable would be a precision optical system of at least 0.25 meters, or a relevant sub-component of a system, or a prototype demonstration of a fabrication, test or control technology. Phase 1 mirror system or component deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost optical systems that can meet flight requirements (including processing and infrastructure issues). Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Technical Need

To accomplish NASA's high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirrors with low mass-to-collecting area ratios.

Specifically needed for potential UVO missions are normal incidence 4-meter (or larger) diameter 5 nm rms surface mirrors; and, active/passive align/control of normal-incidence imaging systems to achieve < 500 nm diffraction limit (< 40 nm rms wavefront error, WFE) performance. Additionally, recent analysis indicates that an Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability of less than 10 pico-meters per 10 minutes.

Specifically needed for potential IR/Far-IR missions are normal incidence 12-meter (or larger) diameter mirrors with cryo-deformations < 100 nm rms.

Also needed is ability to fully characterize surface errors and predict optical performance.

Metrics

In all cases, the most important metric for an advanced optical system (after performance) is affordability or areal cost (cost per square meter of collecting aperture). Current normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100K/m2.

Technology development is required to fabricate components and systems to achieve the following Metrics:

• Areal Cost	< $500k/m2	(for UV/Optical
• Areal Cost	< $100k/m2	(for Infrared)
• Monolithic:	1 to 4 meters	
• Segmented:	> 4 meters	(total aperture)
• Wavefront Figure	< 5 nm rms	(for UV/Optical)
• Cryo-deformation	< 100 nm rms	(for Infrared)
• Slope	< 0.1 micro-radian	(for EUV)
• Thermally Stable	< 10 pm/10 min	(for Coronagraphy)
• Dynamic Stability	< 10 pm	(for Coronagraphy)
• Actuator Resolution	< 1 nm rms	(for UV/Optical)

Optical Components/Systems for potential UV/O missions

Potential UV/Optical missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with < 10 nm rms surface figures and < 10 pm per 10 min stabilty. Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e. 15 kg/m2 for a 5 m fairing EELV vs. 60 kg/m2 for a 10 m fairing SLS). Regarding areal cost, it is necessary to keep the total cost of the primary mirror at or below $100M. Thus, an 8-m class mirror (with 50 m2 of collecting area) should have an areal cost of less than $2M/m2. And, a 16-m class mirror (with 200 m2 of collecting area) should have an areal cost of less than $0.5M/m2.

Key technologies to enable such a mirror include new and improved:

- **Mirror substrate materials and/or architectural designs**
- **Processes to rapidly fabricate and test UVO quality mirrors**
- **Mechanisms and sensors to align segmented mirrors to < 1 nm rms precisions**
- **Thermal control to reduce wavefront stability to < 10 pm rms per 10 min**
- **Vibration isolation (> 140 db) to reduce phasing error to < 10 pm rms**

Also needed is ability to fully characterize surface errors and predict optical performance via integrated opto-mechanical modeling.

Ultra-Stable 1m Class UVOIR Telescopes

1-m class balloon-borne telescopes have flown successfully, however, the cost of such telescopes can exceed $6M, and the weight of these telescopes limits the scientific payload and duration of the balloon mission.

A 4X reduction in cost and mass would enable missions which today are not feasible.

3.1.1 Exoplanet Mission Telescope

A potential exoplanet mission seeks a 1-m class wide-field telescope with diffraction-limited performance in the visible and a field of view > 0.5 degree. The telescope will operate over a temperature range of +10 to -70 C at an altitude of 35 km. It must survive temperatures as low as -80 C during ascent. The telescope should weigh less than 150 kg and is required to maintain diffraction-limited performance over: a) the entire temperature range, b) pitch range from 25 to 55 degrees elevation, c) azimuth range of 0 to 360 degrees, and d) roll range of –10 to +10 degrees. The telescope will be used in conjunction with an existing high-performance pointing stabilization system.

3.1.2 Planetary Mission Telescope

A potential planetary balloon mission requires an optical telescope system with at least 1-meter aperture for UV, visible, near- and mid-IR imaging and multi/hyperspectral imaging.

Optical Components/Systems for potential IR/Far-IR missions

Potential Infrared and Far-IR missions require 12 m to 16 m to 24 meter class segmented primary mirrors with ~ 1 μm rms surface figures which operates at < 10 K.

There are two primary challenges for such a mirror system:

- **Areal Cost of < $100K per m2.**
- **Cryogenic Figure Distortion < 100 nm rms**

Infrared Interferometry Mission Telescope

A balloon-borne interferometry mission requires 0.5 meter class telescopes with siderostat steering flat mirror. There are several technologies which can be used for production of mirrors for balloon projects (aluminum, carbon fiber, glass, etc.), but they are high mass and high cost.

Fabricate, Test & Control Advanced Optical Systems

While Sections 3.1 and 3.2 detail the capabilities need to enable potential future UVO and IR missions, it is important to note that this capability is made possible by the technology to fabricate, test and control optical systems. Therefore, this sub-topic also encourages proposals to develop such technology which will make a significant advance of a measurable metric.

Any Questions?